Patent Application of

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For

TITLE: REFLECTIVE CHOLESTERIC DISPLAYS EMPLOYING LINEAR POLARIZER

FIELD OF INVENTION

The present invention relates to cholesteric displays, and more specifically, to reflective cholesteric displays employing linear polarizer(s). Two display modes have been accomplished and both of them take on black-and-white appearances. The addition of the weak linear polarizer has greatly increased the brightness of the white color while maintaining the black darkness.

BACKGROUND OF THE INVENTION

Cholesteric liquid crystal displays are characterized by the fact that the pictures stay on the display even if the driving voltage is disconnected. The bistability and multistability also ensure a completely flicker-free static display and have the possibility of infinite multiplexing to create giant displays and / or ultra-high resolution displays. In cholesteric liquid crystals, the molecules are oriented in helices with a periodicity characteristic of material. In the planar state, the axis of this helix is perpendicular to the display plane. Light with a wavelength matching the pitch of the helix is reflected and the

display appears bright. If an AC-voltage is applied, the structure of the liquid crystals changes from planar to focal conic texture. The focal conic state is predominately characterized by its highly diffused light scattering appearance caused by a distribution of small, birefringence domains, at the boundary between those domains the refractive index is abruptly changed. This texture has no single optic axis. The focal conic texture is typically milky-white (i.e., white light scattering). Both planar texture and focal conic texture can coexist in the same panel or entity. This is a very important property for display applications, whereby the gray scale can be realized.

Current cholesterics displays are utilizing "Bragg reflection", one of the intrinsic properties of cholesterics. In Bragg reflection, only a portion of the incident light with the same handedness of circular polarization and also within the specific wave band can reflect back to the viewer, which generates a monochrome display. The remaining spectrum of the incoming light, however, including the 50% opposite handedness circular polarized and out of Bragg reflection wave band, will pass through the display and be absorbed by the black coating material on the back surface of the display to ensure the contrast ratio. The overall light utilization efficiency is rather low and it is not qualified in some applications, such as a billboard at normal ambient lighting condition. The Bragg type reflection gives an impression that monochrome display is one of the distinctive properties of the ChLCD.

U.S.Pat. No. 3,704,056 introduces a transmissive display in a way of attaching two linear polarizers between a cholesteric cell structure to enhance the contrast between the image and the background area. The liquid crystalline material is designed in an infrared waveband. A back lighting source is projected on the display screen so that an image will take on the dark background. Since the two polarizers are arranged crossed to each other, the display takes on black state in Grandjean (planar) texture area and white state in focal conic texture area respectively. Unfortunately, such a display mode has been greatly limited its applications in nowadays portable electronic devises.

U.S.Pat. No. 5,796,454 introduces a black-and-white back-lit ChLC display. It includes controllable ChLC structure, the first circular polarizer laminating to the first substrate of the cell which has the same circular polarity as the liquid crystals, the second

circular polarizer laminating to the second substrate of the cell which has a circular polarity opposite to the liquid crystals, and a light source. The display is preferably illuminated by a light source that produces natural "white" light. Thus, when the display is illuminated by the back light, the circular polarizer transmits the 50% component of the incident light that is right-circularly polarized. When the ChLC is in an ON state, the light reflected by the ChLC is that portion of the incident light having wavelengths within the intrinsic spectral bandwidth, and the same handedness; The light that is transmitted through the ChLC is the complement of the intrinsic color of ChLC. Since the transmitted light has right-circular polarization, it will be blocked by the left-circular polarizer. Therefore, this area will be substantially black. When the display is in an OFF state, the light transmitted through the polarizer is optically scattered by the ChLC in focal conic structure. The portion of the incident light that is forward-scattered is emitted from the controllable ChLC structure as depolarized light. The left-circularly polarized portion of the forward-scattered light is then transmitted through the left-circular polarizer, and finally is perceived by an observer. Such black-and-white effect is achieved by the back-lit component and the ambient light is nothing but noise.

U.S.Pat. No. 6,344,887 introduces a method of manufacturing a full spectrum reflective cholesteric display, herein is incorporated by reference. '887 teaches a cholesteric display employing absorptive polarizers with the same polarity but different disposition. The display utilizes an absorptive circular polarizer and a metal reflector film positioned on the backside of the display to guide the second component of the incoming light back to the viewer. However, the shortcoming of the Iodine type absorptive polarizer makes the display to take on a tint of color in the optical ON state, for example, greenish white. The reasons for that are described as follows: Firstly, all the absorptive iodine polarizer has a more or less blue leaking problem which causes non-neutral color of a display device. Secondly, the absorptive polarizer has limited transmission (44%) and polarizing efficiency that causes the second reflection having less intensity than that of the first one. Thirdly, the metal reflector always has a limited reflectivity. Take the Aluminum for example, the reflectivity is in the range of 80~90%. Fourthly, the quarter waveform retardation film can only match a narrow wavelength of the light to generate a circularly polarized light. Addition to the multi-layer surface mismatching, the total

reflection of the back absorptive circular polarizer is around 35%. All those reasons result in a full spectrum cholesteric display appearing non-paper white.

SUMMARY OF THE INVENTION

It is the primary objective of the present invention to realize a reflective cholesteric display with high brightness.

It is another objective of the present invention to utilize linear polarizer(s) to modulate the optically homogeneous cholesteric liquid crystal structure.

It is still another objective of the present invention to use a weak linear polarizer to achieve a paper white reflection in display's focal conic texture.

It is also another objective of the present invention to create a black dark state in display's planar texture.

It is again another objective of the present invention to obtain black dark state by multiple pass absorption of the linear polarizers in display's focal conic texture.

It is still another objective of the present invention to use the optical homogeneous characteristics of the liquid crystal and the linear polarizers' modulation to achieve paper white state in displays' planar texture.

It is also another objective of the present invention to generate black-and-white display by means of the linear polarizer.

It is again another objective of the present invention to generate a full color display by means of the linear polarizer and the micro color filters.

It is a further objective of the present invention to realize a cholesteric display with a ultra low driving voltage.

THEORETICAL BACKGROUND OF THE INVENTION

It is discovered that when the cholesteric liquid crystal material is tuned to a suitable helical pitch and when the display cell structure is satisfied with certain conditions such as the ratio of the cell thickness to the pitch (d/p), an in plane homogeneous cholesteric display can be formed. Such a homo-optical cholesteric phase has no visible color dispersion, no circularly polarization and retardation to the incident light so that a linear

polarizer can be adapted to produce both reflective and transmissive display with black and white characteristics. Color filter can be also adopted to the cell structure to produce a full color display. The display will maintain its merits of long time memory at zero electric field, high information content or resolution, and so on.

The cholesteric liquid crystal display has two essential controllable structures, cholesteric planar structure and focal conic structure.

The planar structure in the present invention is an optically homogeneous structure for the purpose of ultra-high contrast ratio. The structure has less molecular disclination or the defect of liquid crystal orientation and less optical disturbance to the incoming light. Therefore, the application of such planar structure in transmissive display mode will endow the display with high transmittance (bright) when two linear polarizers attached in parallel to the display cell structure, and with high extinction (dark) when two crossed polarizers attached to the display respectively. There is also other reflective display mode wherein a linear polarizer attached to the front substrate and a reflective half-wave plate to the back substrate, the display will take on black dark state. The optical performance of the optically homogeneous structure is similar to the TN structure besides its much stronger twisting power. The pitch of the cholesteric structure is chosen in such a way that the Bragg reflection wave band is out of the visible wavelength so that there is no visible light discerned in the normal direction but a dull red color might be noticed in the oblique direction. Meanwhile the cell thick-to-pitch ratio (d/p) has been chosen in the range of 5-7, which endows the cholesteric material with a strong twisting angle, at least 1,800 degrees or 10π. Such a large twisting power ensures long time display memory when the power is off.

The focal conic structure of the new display structure is the same as traditional cholesteric displays. It is well known that the focal conic structure can be long-term stored in power off state as long as the twisting power is large enough. The shortcoming of short focal-conic storage time in the early days displays, from few seconds to a couple of hours as reported in 1970s and 1980s, is attributed to the low twisting power caused by an insufficient helical pitch and the ratio d/p. Optically, the focal conic structure is a multi-domain structure. One of the major features is light scattering and light depolarization. The strong scattering effect to the incoming light is due to the abrupt

change of indices of refraction among cholesteric domains within the structure. The intensity of the light scattering (sometimes it is also called hiding power) depends on the optical birefringence of the liquid crystal, i.e. delta n, cell thickness and surface condition. The focal conic structure takes on a pure white color because of its optically symmetrical distribution. Similar to the homo-optical performances of cholesteric planar structure mentioned above, the focal conic structure is also optically homogeneous. There is no coloration, polarization or retardation to the incoming light.

The above-mentioned in plane homogeneous properties of both cholesteric planar texture and focal conic texture give a birth to a new category of reflective black-and-white displays by means of linear polarizing modulations. Basically, there are two display modes introduced in the present invention. Firstly, planar texture as the white color state and the focal conic texture as the black state; Secondly, planar texture as the black state while the focal conic texture as the white color state. The former display mode takes the advantage of the two linear polarizers' light-guiding effect in the planar texture and the light multi-pass-absorption effect in the focal conic texture. The latter mode utilizes a linear polarizer and a reflective half-wave plate to obtain a black planar texture and white focal conic texture.

Another main advantage of the present invention is the low driving voltage. Since the helical pitch of cholesteric liquid crystals is chosen in the near-infrared wavelength, the working voltage is much lower than that of the prior art. The phase change voltage in the present invention, for example, is only 12 volts and the phase transition voltage from planar to focal-conic is 3.5 volts.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 demonstrates a schematic sectional structure of a reflective black-and-white display with a weak absorptive linear polarizer attached onto the front substrate of the display cell, and a reflective half wave plate on the back substrate of the display cell.

FIG. 2 demonstrates a schematic sectional structure of a reflective black-and-white display attached with two crossed linear polarizers and a metal reflector.

FIG. 3 demonstrates a schematic sectional structure of a reflective black-and-white display attached with a front absorptive linear polarizer and back reflective linear polarizer.

FIG. 4 demonstrates a schematic sectional structure of a reflective full color display with an absorptive color filter deposit inside the display cell. An absorptive linear polarizer and a reflective half wave plate are also attached to the outside of the cell respectively.

FIG. 5 demonstrates a schematic sectional structure of a reflective black-and-white display attached with two in-parallel linear polarizers and a metal reflector.

DETAILED DESCRIPTION

Referring first to FIG. 1 illustrated is the reflective cholesteric display modulated by a front linear polarizer, a reflective half-wave plate. The natural light **180** reaches the front linear polarizer **160** that is laminated on the first display substrate **130**. A portion of incoming light is filtrated by the polarizer and remaining polarizing light **181** is allowed to pass. When **181** passes the cholesteric film **110** in the planar structure **111** wherein the helical pitch has tuned in IR wavelength, there will be no visible circularly polarization generated. Thus the out-coming light **182** will substantially remain its linear polarization state. The linear polarization **182** then hits on a reflective half wave plate **170**, which turns the incoming light into orthogonal polarization **183**. As the light **183** traveling through planar structure **111,** it remains the same polarization state because the media is in-plane homogeneous. Since light **183** is orthogonal to **182,** it will be substantially cut off by the front polarizer **160**. As a result, a black optical state will be displayed in the planar texture area.

There are three physical matters need to be satisfied with to ensure the optical dark state. Firstly, the selective reflection of circularly polarization must be out-off visible wave bend. The intrinsic Bragg reflection should either in the IR wave bend or in the UV wave bend. The former is more preferable because it has lower driving voltage and faster response time. The helical pitch of the cholesteric molecules, determined by the formula:

$$\lambda = n P > 700 \text{ nm}$$

where "λ" represent the wavelength of the intrinsic Bragg reflection, "n" the average refractive index of the liquid crystal and "P" the helical pitch of the liquid crystal. Therefore, the pitch should be adjusted to over 0.50μm, or more preferably, in the range of 0.50—0.80μm.

Secondly, the frond linear polarizer **160** and the back reflective half plate **170** should be aligned in approximately 45 degrees to achieve 90-degree optical phase change, i.e., "e" component polarization (input) becomes "o" component polarization (output), or vice versa. The letter "e" means the extraordinary component of the incoming light and "o" the ordinary component of it.

Thirdly, the planar structure should design to be substantially single domain structure, which rules out the possibility of depolarization effect due to abruptly changing of the refractive indices among the edges of the domains. Double rubbing or single rubbing the alignment layer(s), deposited on the inner surfaces of display substrates, will be able to realize the required structure. Double surface rubbing is preferred if it were not consider other parameters because of the short relaxation time and uniform domain configuration. As a matter of fact, single rubbing usually gives more balanced performances.

On the other hand, cholesteric focal conic structure **112** is multi-domain structure. The natural light **180** first reaches the front linear polarizer **160** that is laminated on the first display substrate **130**. A portion of the incoming light is filtrated by the polarizer and remaining polarizing light **181** is allowed to pass through the linear polarizer. When **181** passes the cholesteric film **110** in the focal conic structure **112** it will be depolarized by the scattering effect due to abruptly changing of the refractive indices among the domain edges of domains. The depolarized light will split into two parts, forward scattering **185** and backward scattering **184**. The forward scattered light **185** then hit on the reflective half wave plate and is bounced back (see light **186**). The light **186** further passes through focal conic **112** and becomes light **187**. Finally the backward scattering **184** joins with **187**, passing through front polarizer, and emerges to the front of the display as the polarized light **188,** which will be discerned by the viewer. Indeed, the light out of the cholesteric focal conic structure is white light. Perhaps the most important discovery of the present invention is that the white light reflection in the focal conic area can be as high as 50% of the total incoming light while the contrast ratio is maintaining at a high

level. A weak linear polarizer and a specula reflective component attributes to the valuable performance. There are two types of linear polarizers have been used in the present invention. The first one is NITTO NPF-F1228DU, made in Japan, with the following properties:

TRANSMITTANCE (%)			EFFICIENCY (%)
Single	Parallel	Crossed	
48.2	40.7	6.7	84.7

Table 1

The polarizer gives out a good display parameters including whiteness in the focal conic area and the darkness in the planar texture area.

To further improve the whiteness, a weak linear polarizer has been utilized. The weak polarizer can be also called a partial polarizer which means that when a light beam passing the film only partial of it is being polarized and majority part of it will remain the original state. The parameter of the weak polarizer is listed as following:

	Transmittance(%)	L	a^*	b^*	Efficiency(%)	Dichroic ratio
Single	66.3	85.3	-1.0	3.2		
Parallel	49.2	75.8	-0.3	5.4		
Cross	39.999	69.6	-1.5	8.6	32.089	6.011

Table 2

Surprisingly, the unique weak linear polarizer turns out an unexpected result. The brightness of the neutral white optical state is found to be better than a newspaper when the applicant made an apple-to-apple comparison with a sheet of newspaper. It is also found that the blackness of the display in optical "off"state is still satisfactory in the planar texture area within a wide viewing cone. The adoption of the weak linear polarizer produces not only the paper white brightness in focal conic texture but also the darkness

in the planar texture with the help of the specula reflective component. Since the reflective half wave plate is of a specula reflector, it is capable of reflecting the light in a very narrow angle determined by the reflection law. Plus the reflection is not being disturbed in the planar texture area because of the homogeneity in the X-Y plane. Furthermore, the mirror reflected light has the same emergent angle as the display's surface reflection so that the viewer always tends to avoid this viewing direction subconsciously as watching the display. A visual testing has carried out and the result is very promising. The display in planar state really takes on a black dark "off" state over a large viewing angel, despite the fact that there is a light leaking in the specula direction.

By the way, in order to maintain long-term-stable state for both planar and focal conic structures, it is required that an optimal cell parameter, thick-to-pitch ratio, i.e. d/P ratio be in the range of 5 ~ 7. The letter "d" represents the cell thickness and "P", the pitch of liquid crystal.

The weak linear polarizer combined with a specula reflective half wave plate structure, as mentioned above, preduces a high brightness, high contrast and pure black-and-white cholesteric display. Under a suitable driving waveform, both the planar and focal conic structure, at least a portion of them, are interchangeable and long term stable.

Turning now to FIG. 2 illustrated is the reflective cholesteric display modulated by a front linear polarizer **260**, a back polarizer **261** and a specula mirror reflector **270**. When the light **280** passes the front linear polarizer **260**, half of it will be cut off. As the remaining polarizing light **281** reaches the display cell **110** in the planar structure **111**, there will be no visible circularly polarization generated. Thus the out-coming light **282** will substantially remain its linear polarization. The light **282** then passes through the back polarizer **261** and is totally absorbed. As a result, a black optical state will take on in the planar texture area.

When the front light **280** passes the front linear polarizer **260**, half of it will be cut off. As the remaining polarizing light **281** reaches the display cell **110** in the focal conic structure **112** it will be depolarized by the scattering effect due to abruptly changing of the refractive indices among edges of domains. The depolarized light will split into two parts, forward scattering **285** and backward scattering **284**. The forward neutral non-

polarized light **285** then passes back through linear polarizer **261** and becomes linear polarization **286** which then is bounced back by mirror reflector **270** and again through the linear polarizer **261** and maintains its linear polarization **286**. The light **286** then passes through focal conic **112** and becomes a depolarized light **287**. Finally the backward scattering **284** joins with **287** through polarizer **260** and emerges to the front as the polarized light **288**. Indeed, the light **288** out of the cholesteric focal conic structure is white light.

Turning now to FIG. 3 illustrated is the reflective cholesteric display modulated by a front linear polarizer **360**, a back reflective polarizer **361**. Two polarizers are aligned with their absorption axis across to each other. When the light **380** passes the front linear polarizer **360**, half of it will be cut off. As the remaining polarizing light **381** reaches the display cell **110** in the planar structure **111**, there will be no visible circularly polarization generated. Thus the out-coming light **382** will substantially remain its linear polarization. The light **382** then passes through the back polarizer **361** and is totally absorbed by a black coating of the polarizer. As a result " black" state will take on the planar structure area.

When the front light **380** passes through the front linear polarizer **360,** half of it will be cut off. As the remaining polarizing light reaches the cholesteric film **110** in the focal conic structure **112**, it will be depolarized by the scattering effect due to abruptly change of the refractive indices among edges of domains. The depolarized light will split into two parts, forward scattering **385** and backward scattering **384**. The forward neutral non-polarized light **385** then hits on the back reflective linear polarizer **361** and 50% of it becomes linear polarization **386**. The light **386** then passes through focal conic **112** and becomes a depolarized light **387**. Finally, the backward scattering **384** joining with **387** through the front polarizer and converts into polarized light **388,** which is discerned by the viewer. Indeed, the light **388** out of the cholesteric focal conic structure is white light.

The reflective mode display of the present invention has high brightness. Instead of absorptive back linear polarizer as described in FIG.2, the current structure adopts a reflective polarizer. For example, a reflective linear polarizer RDF-B produced in 3M Optical Systems Division is able to reflect one component of polarization and absorb the

other component. The RDF (reflective display film) is made of multi-layer lamination structure of two polymer films with the thickness of 0.122 mm. Each polymer film has a different reflective index and a predetermined thickness so that the interfacial reflections between the multiple layers construct a reflective linear polarization in the direction of reflection axis while the other polarization will be pass through the multi-layer structure in transmission axis. The transmissive component is then absorbed by the underneath black coating layer. Practically, the total reflection in focal conic texture will be approximately 50%, the same reflection as an ordinary newspaper.

Turning now to FIG.4, illustrated is a front color filter positioned inside of the display cell, a front linear polarizer and a reflective half wave plate are laminated to the outside of the display cell respectively. A color filter layer **490**, including red, green and blue patterning, is deposited on the front substrate **430**. The natural light **480** reaches the front linear polarizer **460** that is laminated on the first display substrate **430**. Approximately 50% of incoming light is filtrated by the polarizer and remaining polarizing light **481** is allowed to pass through the linear polarizer. When the polarizing light **481** passes through the front color filter layer **490**, the absorptive coloring material will attenuate it initially. The remaining portion will then reach to the cholesteric film **110** in planar texture area **111** wherein the helical pitch has tuned in the IR wavelength, there will be no visible circularly polarization generated. Thus the out-coming light **482** will substantially remain its linear polarization state. The linear polarization **482** then hits on a reflective half wave plate, which turns the incoming light into orthogonal polarization **483**. As the light **483** traveling through planar structure **111,** it remains the same polarization state because the media is in-plane homogeneous. Since light **483** is orthogonal to **482,** it will be completely cut off by the front polarizer **460**. As a result, a black optical state will be displayed in the planar texture area.

On the other hand, cholesteric focal conic structure **112** is multi-domain structure. The natural light **480** first reaches the front linear polarizer **460** that is laminated on the first display substrate **430**. A portion of incoming light is filtrated by the polarizer and remaining polarizing light **481** is allowed to pass through the linear polarizer. The polarizing light **481** further passes the color filter layer and then the cholesteric film **110**

in the focal conic structure **112** and it becomes depolarized color light depending on the imagewise focal conic patterning. The depolarized light will split into two parts, forward scattering **485** and backward scattering **484**. The forward scattered light **485** then hit on the reflective half wave plate and is bounced back (see light **486**). The light **486** further passes through focal conic **112** and becomes light **487**. Finally it joins with the backward scattering **484**, passing through the color filter layer and front polarizer, and emerges to the front of the display as the color light **488,** which will be discerned by the viewer. Indeed, the light out of the cholesteric focal conic structure is color light with a predetermined tint.

Above all, with the full color optical ON state in focal conic area and the dark optical OFF state in planar area, the present invention achieves a full color reflective display with black background.

Turning now to FIG. 5, illustrated is a black-and-white cholesteric display structure of two in-parallel linear polarizers combined with a metal reflector. When the natural light **580** first reaches the first linear polarizer **560**, 50% of it is filtrated by the polarizer and other 50%, as the light **581**, is allowed to pass. The remaining component then passes the in-plane homogeneous ChLC film without substantial attenuation. The component **581**, passing through the second linear polarizer **561** without attenuation, is reflected by a metal reflector (see light **583**). Furthermore, the light **583** is guided to pass all the way through the second polarizer, ChLC film and the first polarizer without substantially optical loss and finally emerges to the display front surface **588**. In this way, a pure white color will be displayed on the planar texture area.

As the ChLC domains addressed in a focal conic structure **112** the display works at optical "off" state. When the incident light **580** passes through the first polarizer **560**, it will be cut more than 50%. The rest **581** will get to the ChLC cell with focal conic texture and be depolarized by the scattering effect of the LC material. The neutral non-polarized light **585** then passes the second linear polarizer **561**, becomes linear polarized light **586** at the cost of 50% light being cut off. The linear polarized light is then reflected by the aluminum thin layer **570** and passes the ChLC cell again where becoming depolarized light **587** due to the focal conic scattering effect. Similarly, when the non-polarized

remaining light passes the first polarizer, half of it will be absorbed. Finally, only a small portion of the total incident light has a chance to reach the front as a linear polarized light. As a result, the specially designed multiple-pass-absorption creates the optical dark state in the focal conic texture area.